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INFLUENCES OF DIFFERENT IRRIGATION SYSTEMS ON GROWTH AND YIELD OF FOUR EGYPTIAN SUGAR BEET VARIETIES

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Sugar beet (*Beta vulgaris* L.) is a plant cultivated for its highly concentrated sucrose root, which is used in industrial settings to produce sugar. Due to the climate changes that have led to water scarcity, many countries have turned to using modern irrigation systems to save water and maximize the utilization of accessible water assets. In this evaluation, two field experiments were conducted at the National Water Research Center, Water Management Research Institute, Maruit Station, Alexandria Governorate, during 2021/2022 and 2022/2023 fall seasons. This study was conducted to evaluate the behavior and yield characteristics of four sugar beet varieties under various water system frameworks (drip, sprinkler, and furrow). Drip and furrow irrigation systems produced the highest values of quantitative yield indices at 180 days after sowing in both seasons, including root weight, root yield, and fresh top yield, when compared to sprinkler irrigation systems in both seasons and sugar yield in the first season only. In the first season, drip and furrow irrigation systems produced the most root perimeter when compared to sprinkler irrigation systems. Sugar beets grown under drip irrigation used 14.2% less water than those grown under sprinkler irrigation and 35.6% less water than those grown under furrow irrigation. Furthermore, the monogram varieties (BTS3980 and BTS3975) produced the highest values in root yield, sugar yield, and fresh top yield compared to the polygerm varieties (Oscar and Pyramid) in both seasons.

Keywords: sugar beet, drip irrigation, sprinkler irrigation, furrow irrigation

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) gives around 40% of the world's sugar production. It is the primary significant sugar crop in Egypt. Since its inception in 1982, the planted area for this crop has expanded significantly, reaching 597.923 acres by the 2022 season (Hadhad et al., 2022 and Shaltout and Ramadan, 2024). This crop is crucial as it thrives on newly reclaimed land, yields high sugar content, requires less water than sugarcane, and produces substantial amounts of sugar. Improving on-farm water management can save labor or soil and increase crop yields. In recent years, due to increased population pressures and the continued demand for increased food quantity and quality. For that, Egypt has been working hard on a plan for improving agricultural efficiency to cope with population growth. Since water is the most important factor for plant production, improving irrigation management seems essential as a prerequisite for improving the water delivery system in the Nile Delta and the reclaimed lands. Many researchers have studied the effect of different irrigation methods and systems on various crops particularly sugar beet. For example, Kassem et al. (2022) assessed the effectiveness of subsurface drip irrigation systems in Egypt by evaluating the highest root and sugar yields. Özbay and Yildirim (2018) stated that irrigation strategies significantly impact root and sugar yields. For example, in drip irrigation systems, water usage and evaporation were about 11% lower compared to sprinkler systems. This conservation effort enhanced water use efficiency to 15.2 kg m^{-3}. Additionally, El Hamdi et al. (2017) reported that sugar beets irrigated with a center pivot system exhibited superior yield metrics including root length, perimeter, fresh weight, and overall yield compared to those grown under a sprinkler system, measured 190 days after sowing across two growing seasons. The center pivot system yielded significantly the highest sugar and purity percentages compared to the fixed sprinkler. Masri et al. (2015) found that trickle-irrigated sugar beet plants with 75% IWR exhibited the highest sucrose, purity, and extractable sugar percentages over two seasons, as well as white sugar yield in the second season. In contrast, sprinkler irrigation at 100% IWR produced the greatest root weight, root count, purity percentage, and root yield across both seasons. For optimal sugar beet growth in sub-damp conditions using trickle irrigation, a complete water system is recommended to maximize root and sugar yields (Yetik and Candoğan, 2022). Additionally, Jahedin et al. (2012) found that water use in drip irrigation is 50% lower than in furrow irrigation, though root yield differences are minimal between the two methods. Therefore, trickle irrigation systems are advised in water-scarce areas. Furthermore, Tognetti et al. (2003) reported that drip irrigation is compatible with low-pressure sprinkler irrigation for sugar beet cultivation in semiarid regions, providing advantages for root yield and sucrose accumulation.

On the other hand, the process of water conservation does not stop at choosing the irrigation system only, but rather depends on the type of genetic composition and the varieties used in agriculture. Accordingly, there are many studies conducted with the aim of studying the extent to which different varieties are affected by agricultural and irrigation systems and the impact of this on production and growth. For example; Shaaban et al. (2010) and Stevens et al. (2008) demonstrated varietal differences between three sugar beet varieties under salinity stress conditions. El-Sheikh et al. (2009) reported a significant varietal variation within all tested genotypes under three harvesting dates in root fresh weight and yield/fed. Enan et al. (2009) as the length highlighted that sugar beet varieties exhibit variations in root yield, as well as the perimeter of the roots under different levels of N and Mo fertilization. On the other hand, Shalaby et al. (2011) conducted a study on three genotypes (Gazella, Carola, and Lola) and found differences in their growth, yield, and mineral contents under Egyptian conditions.

Also, Marinković et al. (2008) studied the impact of water deficiency on sugar beet leaf yield, finding that the highest yields, ranging from 25.03 to 28.96 t/ha, occurred under 30% water deficiency. Variations in climate and sugar beet varieties were attributed to the differences in leaf yields observed in the study.

Hussein et al. (2008) reported that root diameters ranged from 5.2 to 6.35 cm, primarily due to differences in sugar beet varieties, measurement methods, and irrigation schedules. Studies have demonstrated that varying irrigation practices significantly affect sugar beet yields (Topak et al., 2016). Ali and Burak (2022) found that irrigation treatments notably influenced water productivity (WP) values, statistically significant at the 0.05 level over two years. Moreover, Yetik and Candoğan (2002) indicated that WP values ranged from 7.45 to 9.57 kg m^{-3}, while irrigation water productivity (IWP) values ranged from 9.04 to 10.34 kg m^{-3}. From all previous studies it could be discovered that the maximum sugar and root yield could be achieved with minimal water usage based on the type of variety and the suitable irrigation methods. This study aimed to enhance sugar beet productivity and water use efficiency (WUE) through evaluation of the responses of mono- and poly-germ sugar beet varieties to different irrigation systems. And identifying the suitable irrigation system to get the highest root and sugar output.

MATERIALS AND METHODS

1. Field Tests

During the fall seasons of 2021-2022 and 2022-2023, two field experiments were conducted at the National Water Research Center, Water Management Research Institute, Maruit Station, Alexandria Governorate. The varieties included two mono-microbe assortments (BTS3980 and BTS3975) and two poly-microorganism assortments (Oscar and Pyramid). Seeds were sown 20 cm apart in hills on October 20th in the first season and October 15th in the second. After forty days, seedlings were thinned to one plant per hill. The experiment followed a split-plot design with three replications in both seasons.

2. Sugar Beet Varieties

In this study, four sugar beet varieties were used and the source and the pedigree of these varieties are illustrated in Supplementary Table (S1).

3. Irrigation Systems

3.1. Drip irrigation

The drip irrigation system consists of a 63 mm primary conveyance pipe with 16 mm self-regulating polyethylene laterals discharging at approximately 2 l h^{-1}. The gated pipes made of aluminum and 150 mm in perimeter, feature slide gates spaced 0.75 m apart, each discharging 3.0 m^3 h^{-1}. These are directly connected to the water pump and located at the head of the irrigated field, across the furrows.

3.2. Sprinkler irrigation

In the second span (S-II), stationary plate sprinklers (SPS 2.5) were installed at a height of 2.5 meters, while in the third span (S-III), they were set at 1 m (SPS 1). Both had pressure controllers set to 140 kPa.

3.3. Furrow irrigation

In the experiment, a furrow irrigation system was installed shortly after sugar beet seeding. The control unit included a pressurized water supply, flow meter, pressure gauge, and control valves. The delta water stream rate for the wrinkle technique was 2.4 m^3 h^{-1} per wrinkle using the gated pipe. Water flowed downstream for five minutes along the 63 m blocked-end furrow. Advance and recession times were measured every 5 m along this length.

4. Main Soil Physical Characteristics and Climate Data of the Maruit Research Station

The data relating to the main soil physical characteristics and the average climate data of the Maruit research station were collected from soil and metrology units at Maruit research station (Supplementary Table S1, Table S2, and Table S3).

5. Data Recorded

On the harvesting date (30 April), ten random plants were sampled from each experimental plot for evaluation.

5.1. Root yield components

A- Root weight (g) was recorded 180 days after sowing.

B- Root diameter (cm) was recorded 180 days after sowing.

C- Root length (cm) was recorded 180 days after sowing.

5.2. Root, sugar, and top yields

At harvest, plants in the two guarded ridges were used to determine the root, sugar, and fresh top yields based on the three parameters blow:

A: Root production (ton fad^{-1}).

B: Sugar yield (ton trend), not solely determined by multiplying root yield by sucrose percent.

C: Fresh top yield (ton fad^{-1}).

5.3. Quality characters

A- Hand Refractometer was used to determine the total soluble solids (TSS).

B- The sucrose percentage was determined using a sucrose refractometer.

C- The purity percentage was determined using the method of Carruthers and Oldfield (2013) as follows:

$$Purity = \frac{TSS\%}{Sucrose\%}$$

Water use efficiency (WUE) was assessed for both root and sugar yields.

$$\text{WUE}_{\textit{root yield}}\, rootyield\ \text{m}^3$$

$$\text{WUE}_{\textit{sugar yield}}\, rootyield\ \text{m}^3$$

RESULTS

1. Analysis of Variance for Root Yield Components

Table (1) presents the mean squares of three irrigation systems for sugar beet varieties during the fall seasons of 2021-2022 and 2022-2023. In the initial season, the analysis of variance indicated that irrigation systems, root weight, and root length significantly influenced root yield components at *P 0.05*. During the first season, significant differences ($P < 0.05$) were observed in the interaction of sugar beet varieties, irrigation systems, root weight, and root length. In the following season, significant differences ($P \leq 0.05$) were observed in root weight and root volume among irrigation systems, while root diameter varied significantly among varieties. Additionally, there was a significant interaction between irrigation systems and varieties regarding root length.

Table (1). Analysis of variance for root weight, root diameter and root length in 2022 and 2023 fall seasons.

S.O.V.	d.f.	Root weight (kg)		Root perimeter (cm)		Root length (cm)	
		21/22	22/23	21/22	22/23	21/22	22/23
Blocks	2	0.01	0.01	45.85	1.13	3.74	0.42
Irrigation	2	0.65*	1.50**	21.01	324.24**	16.49	38.01*
Error (a)	4	0.09	0.04	47.28	13.71	6.89	2.37
Varieties	3	0.01	0.12	11.73	53.66**	42.85**	2.37
Cult.× Irrig.	6	0.17**	0.01	50.43*	9.89	25.62*	29.42*
Error (b)	18	0.03	0.04	12.76	10.22	7.06	10.26

2. Root Weight

Table (2) shows that root weight per plant of sugar beet varieties significantly increased ($P \leq 0.05$) in both seasons under the drip irrigation system (1.13 and 1.23 kg) and furrow irrigation system (1.04 and 1.39 kg), compared to the sprinkler irrigation system (0.69 and 0.72 kg). Which mean the interaction between irrigation systems and varieties significantly affected root weight per plant ($P < 0.05$) only in the first season, with the drip irrigation system combined with the polygerm variety Oscar yielding the highest root weight of 1.34 kg per plant. While, the dissimilar effect happened with sprinkler irrigation system with the same polygerm variety, produced the lost root weight per plant (0.43 kg). In the second season, there was no interaction between the irrigation systems with mono-germ and polygerm varieties.

Table (2). Effect of irrigation systems, varieties and interaction between them on root - weight plant 1 kg, root perimeter (cm) and root length (cm) of sugar beet during two fall seasons of 2021/22 and 2022/23.

Irrigation systems	**2021/22**					**2022/23**				
	Varieties									
	Root - weight plant 1 kg									
Irrigation	**BTS 3980**	**BTS 3975**	**Pyra-mid**	**Oscar**	**Mean**	**BTS 3980**	**BTS 3975**	**Pyramid**	**Oscar**	**Mean**
Drip	1.18	0.87	1.11	1.34	1.13a	1.26	1.38	1.09	1.20	1.23a
Sprinkler	0.86	0.93	0.52	0.43	0.69b	0.74	0.84	0.65	0.63	0.72b
furrow	0.86	1.03	1.11	1.18	1.04a	1.48	1.55	1.30	1.24	1.39a
Mean	0.96	0.99	0.91	0.98	0.96	1.16	1.25	1.01	1.02	
L.S.D. 0.05 Irrigation (Irrig.)			0.34					0.22		
Varieties (Var.)			N.S.					N.S.		
Ir. × Var.			0.30					N.S.		
	Root perimeter (cm)									
Drip	28.37	26.30	28.53	31.27	28.62a	35.4	34.6	30.90	32.80	33.42a
Sprinkler	28.75	31.70	22.93	20.67	26.01b	27.14	28.53	20.60	21.40	24.41b
furrow	27.30	24.63	25.10	30.60	26.91a	33.29	36.0	33.50	30.90	33.42a
Mean	28.14a	27.54ab	25.52b	27.51ab	27.18	31.94ab	33.04a	28.33b	28.36b	30.42
L.S.D. 0.05 Irrigation (Irrig.)			N.S.					4.19		
Varieties (Var.)			N.S.					3.16		
Ir. × Var.			6.12					N.S.		
	Root length (cm)									
Drip	34.47	31.45	28.40	31.03	31.34	30.20	27.50	30.87	31.90	30.13b
Sprinkler	35.00	42.97	30.73	28.87	34.39	34.20	38.90	31.10	29.90	33.52a
furrow	33.67	32.30	31.87	33.60	32.86	33.35	31.30	33.18	33.19	32.75b
Mean	34.38a	35.57a	30.33b	31.17 b	32.86	32.60	32.56	31.71	31.66	32.13
L.S.D. 0.05 Irrigation (Irrig.)			N.S					1.74		
Varieties (Var.)			2.63					N.S.		
Ir. × Var.			4.56					5.49		

2.2. Root perimeter

In the first season, the three irrigation systems showed no significant differences in root perimeter (Table 2). However, in the second season, drip and furrow irrigation systems differed significantly from sprinkler systems at $P < 0.05$, with a root perimeter of 33.42 cm. On the other hand, results in Table (2) indicate that significantly there was an effect of the irrigation system on root perimeter in the first season, while, in the second season, the monogerm variety BTS3975 has the highest root perimeter (36 cm) and the polygerm variety, pyramids gave the lost root perimeter (20.6 cm). Furthermore, root perimeter can be affected by the interaction between irrigation systems and varieties, for example, in the first season the highest root perimeter (31.7 cm) was detected in BTS 3975 under the sprinkler irrigation system (Table 2). While the lowest root perimeter (20.67 cm) was detected in Oscar under the sprinkler irrigation system. In addition, in the second season the highest root perimeter (36 cm) was detected in BTS 3975 under the furrow irrigation system (Table 2). While the lowest root perimeter (21.40 cm) was detected in Oscar under the sprinkler irrigation system. Which explain the effect of irrigation system and varieties in root perimeter.

2.3. Root length (cm)

The results in Table (2) strongly show that, there are no significant differences at $P \leq 0.05$ among the three irrigation systems at the first seasons. However, the sprinkler irrigation system recorded a significantly high root length in the second season (38.9 cm) at $P \leq 0.05$. For the varieties in the first season, BTS 3975 variety showed the highest root length (42.97 cm) under the sprinkler system, while the Pyramid variety showed the lowest root length (28.4 cm) under the drip system see (Table 2). Also, in the second season, the BTS 3975 variety show the highest root length (38.9 cm) under the sprinkler system and showed the lowest root length (27.5 cm) under the drip system.

3. The Analysis of Variance on Yield Characters

Irrigation systems notably affected root, sugar, and fresh top yield at P 0.05 during the first two seasons, as shown by the analysis of variance in Table (3). In the first season, the varieties significantly affected root and new top yields ($P \leq 0.05$). In the second season, the yields of root, sugar, and fresh top differed significantly among varieties in both seasons. The interaction between water system frameworks and varieties was highly significant in the first season and notable with sugar and new top yield in the second season at $P \leq 0.05$.

Table (3). Analysis of variance of root, sugar and fresh top yield for sugar beet varieties as affected by irrigation systems in 2022 and 2023 fall winter seasons.

S.O.V.	d.f.	Root yield (ton fad^{-1})		Sugar yield (ton fad^{-1})		Fresh top yield (ton fad^{-1})	
		21/22	**22/23**	**21/22**	**22/23**	**21/22**	**22/23**
Blocks	2	4.26	32.59	0.22	1.17	0.7	1.28
Irrigation	2	300.97*	877.54**	4.73*	21.04**	70.46*	46.45**
Error (a)	4	20.50	15.17	0.28	0.62	7.13	0.58
Varieties	3	38.50**	76.43**	0.33	2.73**	24.36**	17.25**
Cult. × Irrig.	6	77.20**	12.45	2.31**	0.49	43.28**	25.36**
Error (b)	18	3.83	8.82	0.20	0.32	3.42	2.91

3.1. Root yield (ton fad^{-1})

3.1.1. Impacts of irrigation systems

Table (4) clearly shows that the root yield of sugar beet varieties was affected by irrigation systems in both seasons. The sprinkler irrigation system recorded the lowest yield (18.17 and 17.38 ton fad^{-1}) in the first and second seasons, respectively, while there was no significant difference at $P \leq 0.05$ between the drip and furrow irrigation systems in either season.

3.1.2. Impact of varieties

In the first season, the polygerm variety pyramids experienced a root yield loss of 21.14 ton fad^{-1}, with no significant differences between the monogerm varieties (BTS3980 and BTS3975) and the polygerm variety Oscar at $P \leq 0.05$, as shown in Table (4). In the following season, the monogerm varieties PTS3970 and BTS3975 achieved notably higher root yields at $P \leq 0.05$, recording 30.03 and 29.25 ton fad^{-1}, respectively, compared to the polygerm varieties Pyramids and Oscar, which yielded 24.01 and 25.46 ton fad^{-1}, respectively.

3.1.3. Effects of varieties and irrigation systems interaction

In the first season, the monogerm variety (BTS3980) achieved the highest root yield (30.9 ton fad^{-1}) with a drip irrigation system, while the polygerm variety (Pyramid) had the lowest yield (12.17 ton fad^{-1}) using a sprinkler system. This interaction is detailed in Table (4). In the following season, there was no significant impact ($P \leq 0.05$) from the interaction between the irrigation systems and varieties.

Table (4). Effect of irrigation systems, varieties and interaction between them on root yield (ton fad^{-1}), fresh top yield (ton fad^{-1}) and sugar yield (ton fad^{-1}) of sugar beet during two winter seasons of 2021/22 and 2022/23.

Irrigation systems	2021/22					2022/23				
	Varieties									
	Root yield (ton fad^{-1})									
Irrigation	**BTS 3980**	**BTS 3975**	**Pyramid**	**Oscar**	**Mean**	**BTS 3980**	**BTS 3975**	**Pyramid**	**Oscar**	**Mean**
Drip	30.90	23.48	24.16	30.03	27.15^{a}	33.20	31.29	30.70	29.40	31.15^{a}
Sprinkler	24.07	23.47	12.17	12.97	18.17^{b}	22.00	20.77	12.27	14.50	17.38^{b}
furrow	23.40	25.63	27.07	29.90	26.50^{a}	34.90	35.70	29.10	32.50	33.05^{a}
Mean	26.12^{a}	24.19^{a}	21.14^{b}	24.30^{a}	23.94	30.03a	29.25^{a}	24.01^{b}	25.46b	27.19
L.S.D 0.05 Irrigation (Irrig.)			5.13					4.41		
Varieties (Var.)			1.938					2.94		
Irrig. × Var.			6.08					N.S.		
	Fresh top yield (ton fad^{-1})									
Drip	14.33	7.52	11.51	15.20	12.14^{a}	13.80	8.20	11.40	13.87	11.82^{b}
Sprinkler	13.70	12.04	4.67	4.37	8.65^{b}	13.17	11.2	7.50	4.63	9.13^{c}
furrow	12.70	12.97	12.90	14.57	13.3^{a}	13.13	11.63	12.80	14.30	12.97^{a}
Mean	13.58^{a}	10.84^{b}	9.65^{b}	11.38^{b}	11.36	13.34^{a}	10.34^{b}	10.57^{b}	10.93^{b}	11.29
L.S.D 0.05 Irrigation (Irrig.)			3.03					0.86		
Varieties (Var.)			1.83					1.69		
Irrig. × Var.			3.17					2.92		
	Sugar yield (ton fad^{-1})									
Drip	4.50	3.20	4.04	4.50	4.06^{a}	5.42	5.05	5.40	4.74	5.15^{a}
Sprinkler	3.60	3.80	1.89	2.04	2.83b	3.76	3.57	2.16	2.60	3.02^{b}
furrow	3.10	3.27	3.92	4.24	3.63^{ab}	6.26	6.03	4.91	4.90	5.52^{a}
Mean	3.73^{a}	3.42^{ab}	3.28 b	3.59^{ab}	3.51	5.14^{a}	4.88^{a}	4.15^{b}	4.08^{b}	4.56
L.S.D 0.05 Irrigation (Irrig.)			0.52					0.89		
Varieties (Var.)			0.53					0.56		
Irrig. × Var.			0.90					N.S		

3.2. Fresh top yield (ton fad^{-1})

3.2.1. Effect of irrigation systems

In the first season, there was no significant difference between the drip irrigation system (12.14 ton fad^{-1}) and the furrow irrigation system (13.3 ton fad^{-1}) at *P 0.05*, while the sprinkler irrigation system produced the lowest yield (8.65 ton fad^{-1}). These findings are presented in Table (4). In the subsequent season, the furrow irrigation system recorded the highest yield (12.97 ton fad^{-1}), whereas the sprinkler system again had the lowest (9.13 ton fad^{-1}).

3.2.2. Impact of varieties

Table (4) shows that the monogerm variety BTS3980 achieved the highest significant new top yield in both seasons, with totals of 13.58 and 13.34 ton, respectively. Additionally, there was a significant difference between the monogerm variety BTS3975 and the polygerm varieties Pyramids and Oscar, with a *P* value of 0.05 in both seasons.

3.2.3. The impact of how different varieties and irrigation systems interact

In the second season, the furrow irrigation system with the polygerm variety Oscar produced the highest fresh top yield (14.30 ton fad^{-1}) while the sprinkler irrigation system and the polygerm variety Oscar produced the lowest fresh top yield (4.63 ton fad^{-1}). In the first season, the drip irrigation system combined with the polygerm variety Oscar resulted in the highest fresh top yield ton fad^{-1} (15).

3.3. Effect of sugar yield

3.3.1. Impact of irrigation systems

Table (4) shows that drip and furrow irrigation systems significantly increased sugar yield at $P \leq 0.05$, producing 4.06 and 3.6 ton ha^$^{-1}$ in the first season and 5.15 and 5.52 ton ha^$^{-1}$ in the second season, respectively. In contrast, the sprinkler irrigation system resulted in lower sugar beet yields of 2.83 and 3.02 ton ha^$^{-1}$ during the first and second seasons.

3.3.2. Impact of varieties

Table (4) shows that the polygerm variety Pyramid had the lowest sugar yield (3.28 ton fad^{-1}) in the initial season. In contrast, there was a significant difference in yields between the monogerm varieties BTS3980 and BTS3975 and the polygerm variety Oscar. In the second season, the highest sugar beet yields were from the monogerm varieties BTS3980 and BTS3975, yielding 5.14 and 4.88 ton fad^{-1}, respectively. Meanwhile, the polygerm varieties Pyramid and Oscar recorded the lost sugar beet yield (4.15 and 4.08 ton fad^{-1}), respectively.

3.3.3. Impact of varieties and irrigation systems

In the first season, Table (4) highlights the interactions between sugar beet varieties and irrigation systems. The combination of drip irrigation with the monogerm variety BTS 3980 and the polygerm Oscar yielded the highest sugar output of 4.5 ton fad^{-1} each. Conversely, the polygerm variety Pyramid combined with sprinkler irrigation resulted in a loss of 1.89 ton fad^{-1}. In the second season, the interactions between the monogerm and polygerm sugar beet varieties with the irrigation systems showed no significant differences.

Table (5) displays the mean squares of various quality attributes for sugar beet varieties under three irrigation systems during the 2021/22 and 2022/23 seasons. All quality characteristics, except for TSS % in the first season, were significantly affected by the irrigation systems for sucrose % and TSS % at $P < 0.05$. Conversely, purity percentage showed no statistical significance in either season. The interaction between varieties and irrigation was significant for sucrose % and TSS % at $P < 0.05$ in both seasons.

Table (5). Analysis of variance of some quality characteristics of sugar beet varieties as affected by irrigation systems in 2021/22 and 2022/23 fall seasons.

S.O.V.	d.f.	T.S.S.%		Sucrose %		Purity %	
		21/22	22/23	21/22	22/23	21/22	22/23
Blocks	2	0.86	0.01	0.03	0.03	2.81	2.18
Irrigation (Irrig.)	2	8.83	8.35*	10.12**	5.14*	41.91	1.42
Error (a)	4	1.70	0.74	0.35	0.69	7.36	0.53
Variety (Var.)	3	4.10**	2.15	1.40*	1.08	5.23	1.69
Var. x Irrig.	6	1.33*	2.13*	0.86**	1.23*	10.97	0.46
Error (b)	18	0.42	0.71	0.19	0.37	5.44	0.61

4. Effect of Irrigation Systems and Varieties and Interaction Between Them on Quality Characteristics

4.1. Total Soluble Solvent percentage (TSS %)

From the results it was found that there was no significant difference in TSS % among the three irrigation systems at the first season, while in the second season, the sprinkler system (21.8%) was a significantly outperformed both the drip and furrow systems (20.4% each) at $P \leq 0.05$. Furthermore, the Pyramid polygerm variety achieved a highly percentage from TSS% (21.57%) compared with the other two varieties in the first season. Meanwhile, in the second season there is no significant difference in TSS % at $P \leq 0.05$ between the four varieties (Table 6). For the effect of various irrigation system with varieties on the percentage of TSS, at the first season, the pyramid variety was shown the highest TSS % (21.57 %) under the sprinkler system and the lowest TSS % was 18.43% under the furrow system. Additionally, in the second season the Oscar variety was shown the highest TSS % (22.16%) under the sprinkler system and the lowest TSS % (18.43%) was reported under the furrow system.

4.2. Proportion of sucrose

4.2.1. Impact of water system frameworks

Table (6) illustrates the significant effects of the irrigation system, variety, and their interactions. Under the sprinkler irrigation system, sucrose percentages notably rose at *P 0.05* in both seasons, reaching 15.62% and 17.55%, respectively. Moreover, in the first season, polygerm variety, Pyramid and Oscar formed the highest significant value at $P \leq 0.05$ of sucrose percentage (15.02 and 14.94%), meanwhile, monogerm variety, BTS3980, and BTS3975 produced the lowest sucrose percentage (14.23 and 14.38%), respectively. In the second season, at $P \leq 0.05$, no significant differences were found between the varieties. Furthermore, during the primary season, the interaction between the sprinkler system and the monogerm variety BTS3975 resulted in the highest sucrose percentage at 16.17%. Whereas, furrow irrigation system with monogerm variety, BTS3980 recorded the lowest sucrose % (13.2%). The following season, the interaction between the sprinkler irrigation system and polygerm Oscar at $P \leq 0.05$ resulted in the highest sucrose percentage (17.8%), while the same variety recorded the lowest sucrose percentage (15.1%) with the wrinkle irrigation system.

Table (6). Effect of irrigation systems, varieties and interaction between them on total soluble solids percentage (TSS %), sucrose percentage and purity percentage of sugar beet during two fall seasons of 2021/22 and 2022/23.

Irrigation systems	2021/22					2022/23				
	Varieties									
	Total soluble solids percentage (TSS %)									
Irrigation	**BTS 3980**	**BTS 3975**	**Pyramid**	**Oscar**	**Mean**	**BTS 3980**	**BTS 3975**	**Pyra-mid**	**Oscar**	**Mean**
Drip	19.97	18.97	20.63	19.20	19.69	20.20	19.80	21.40	20,20	20.40[b]
Sprinkler	20.03	21.30	21.57	21.27	21.04	21.90	21.33	22.00	22.16	21.85[a]
Furrow	18.67	18.43	20.77	19.93	19.45	21.30	21.00	20.90	18.60	20.40[b]
Mean	19.56[b]	19.57[b]	20.99[a]	20.13 b	20.06	21.13a	20.71b	21.43a	20.32b	20.90b
L.S.D 0.05 Irrigation (Irrig.)			N.S.					0.97		
Variety (Var.)			0.64					N.S.		
Irrig. × Var.			1.11					1.44		
Sucrose percentage										
Drip	14.57	13.7	14.85	14.97	14.52[b]	16.20	16.07	17.00	16.20	16.36[b]
Sprinkler	14.93	16.17	15.63	15.73	15.62[a]	17.60	17.20	17.60	17.80	17.55[a]
furrow	13.20	13.27	14.57	14.13	13.79[c]	17.20	16.80	16.80	15.10	16.48[b]
Mean	14.23[b]	14.38[b]	15.02[a]	14.94[a]	14.64	17.00	16.69	17.13	16.35	16.79
L.S.D 0.05 Irrigation (Irrig.)			0.67					0.94		
Variety (Var.)			0.44					N.S.		
Irrig. × Var.			0.75					1.04		
	Purity percentage									
Drip	73.00	72.30	74.80	78.23	74.59	80.20	81.30	79.50	80.20	80.30
Sprinkler	74.50	75.70	72.50	74.00	74.18	80.30	80.60	79.76	80.50	80.29
Furrow	70.73	72.00	71.03	70.90	71.17	80.50	80.90	80.60	80.87	80.72
Mean	72.74	73.33	72.78	74.38	73.31	80.33	80.93	79.95	80.52	80.43
L.S.D 0.05 Irrigation (Irrig.)			N.S.					N.S.		
Variety (Var.)			N.S.					N.S.		
Irrig. × Var.			N.S.					N.S.		

5. Water use efficiency (WUE)

Table (7) shows the average water usage of various irrigation systems over the two seasons studied. The trickle irrigation system used the least water (924 and 835 m^3), followed by the sprinkler irrigation system (1100 and 950

m^3) and the furrow irrigation system (1386 and 1318 m^3). Additionally, Table (8) illustrates the yield produced per cubic meter of water for roots, sugar, and new tops. The drip irrigation system attained the highest root, sugar, and fresh top yields (282, 44, and 116 kg m^{-3}) respectively, While the sprinkler irrigation system gave the lowest yield for roots, sugar, and fresh top yields (119, 20 and 64 kg), respectively.

Table (7). The quantities of water used during the two studied seasons through different irrigation systems (m^3).

Irrigation systems	2021/2022	2022/2023	Mean
Drip	1232.0	1113.3	1172.7
Sprinkler	1466.7	1266.7	1366.7
Furrow	1848.0	1820.3	1820.3

Table (8). Average production of water cubic meter as root, sugar and fresh top yields (kg m^{-3}).

Irrigation systems	Root yield (kg m^{-3})	Sugar yield (kg m^{-3})	Fresh top yield (kg m^{-3})
Drip	282	44	116
Sprinkler	119	20	64
Furrow	153	19	55

DISCUSSION

This research was conducted to study the performance of four sugar beet varieties under different irrigation systems. From the present study, it was found that the drip and furrow irrigation systems produced the highest values for yield in both seasons, compared with sprinkler irrigation systems. These results are in line with Marinković et al. (2008), Jahedi et al. (2012), El Hamdi et al. (2017), Özbay and Yildirim (2018), Kassem et al. (2022) and Yetik and Candoğan (2022). On the other hand, when the sprinkler irrigation systems were compared with other systems, it was found that the drip and furrow irrigation systems produced the most root perimeter in the first season. Also, the drip irrigation system consumed less irrigation water than sprinkler and furrow systems by 14.2% and 35.6%, respectively (Marinković et al., 2008; Jahedi et al., 2012; Masri et al., 2015; Özbay and Yildirim, 2018 and Yetik and Candoğan, 2022). The reason behind that is the way that the drip water system framework holds water and supplements around the root, which helps to form a good vegetative system, which is reflected the root weight, root, and fresh top yield (El-Sheref, 2007). While, the sprinkler irrigation system loses part of the water on the leaves, which exposing it to evaporation and does not reach the root of the plant with the same efficiency as drip irrigation, the furrow irrigation system loses part of the water in the spaces between the plant and the lines, thus increasing water consumption. The sprinkler irrigation system produced the highest percentage of sucrose due to the inverse relationship between root weight and percentage of sucrose, where, the sprinkler irrigation system recorded the lowest root weight per plant.

In this context, it could be said that the variation between varieties in vegetative, crop, and technological traits, may be due to genetic differences, including mongyrm and polygerm, and also to different irrigation systems and climatic conditions. These results agree with Marinković et al. (2008), Stevens et al. (2008), El-Sheikh et al. (2009), Enan et al. (2009), Shaaban et al. (2010), Hussein et al. (2008) and Shalaby et al. (2011). They studied the effect of various irrigation system and different varieties on the final beet crop yield and they found epistatic relationship between the choosing of appropriate irrigation system, variety selection and final crop yield. In addition, the study showed that Oscar polygerm variety was greatly affected, negatively or positively, by the different irrigation systems, while the other varieties had no clear differences in the interaction with the irrigation systems used. These results are in line with Mehanna et al. (2017), who studied the interaction of irrigation x varieties and detected a significant response. At the end, proper irrigation is crucial for a healthy and bountiful sugar beet crop with superior yields and quality potential. Finally, implementing a water system shortly before the soil water level drops to 60% and replenishing available soil moisture to the appropriate root zone can significantly enhance the production of quality, high-yield sugar beet crops (Pereira et al., 2012 and Carruthers and Oldfield, 2013).

CONCLUSIONS

Root and sugar yield are critical for sugar beet production, agricultural decision makers in developing nations must enhance crop output, considering the challenges related to water scarcity and more competition for freshwater from industrial and domestic users. Therefore, effective irrigation water management is essential. So, in this research it was found that the experiment's drip water system had a significant effect on plant growth and yield. Additionally, sugar beets grown in a drip irrigation system required 14.2% less water than sugar beets grown in a sprinkler system and 35.6% less water than sugar beets grown in a furrow irrigation system. In the setting that a trickle water system framework yields the most root, sugar, and new top yields per cubic meter of water, though a sprinkler water system framework yields the least root, sugar, and new top yields per cubic meter of water. Then again, for the assortments that were utilized in this review, it was found that there are no reasonable huge contrasts between the assortments in every one of the attributes under study.

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Supplementary Table (S1). List of sugar beet (*Beta vulgaris*) varieties that used in this study.

Serial number	Variety	Code	Genotypes handling category	Seed type	Page
A	BTS3980	A,H,DE,512	Commercial var.	Mono-germ	B4
B	BTS3975	A,H,FR,512	Commercial var.	Mono-germ	B4
C	Oscar	G,U,NL,2277	Commercial var.	Polygerm	B25
D	Pyramide	A,H,FR,2063	Commercial var.	Polygerm	B27

Key symbols used in the classification of sugar beet, *Beta vulgaris* varieties are shown below: A: Use for sugar, H: 2n x 2n, G: 2n x 4n, M: 2n x 4n, U: Use for fodder, E: Diploid 2n, F: Tetraploid 4n., DE: Germany, FR: F rance, NL: Netherlands

Supplementary Table (S2). Main soil physical characteristics.

Mechanical analysis (Particles %)					Moisture content (% by weight)			
Clay	Silt	Fine sand	Coarse sand	Texture	Bulk density (g/cm)	Field Capac-ity %	Wilting point %	Available Water %
10.93	48.85	38.25	1.73	Silty loam	1.31	31	14	17

Supplementary Table (S3). The average climate data of the Maruit Research Station throughout the 2021/2022 and 2022/2023 seasons.

Month	Temp. (max. °C)	Temp. (min. °C)	Temp. (average °C)	Relative humidity (%)	Wind speed (m s^{-1})	Rain (mm)
Oct.	30.6	18.3	24.5	71.2	11.4	3.3
Nov.	27.6	14.7	21.2	78.6	8.3	3.7
Dec.	23.7	10.7	17.2	73.7	6.5	14.9
Jan	20.5	8.6	14.6	74.9	4.3	25.0
Feb	19.1	7.5	13.3	68.7	3.9	21.1
March	20.1	8.9	14.5	65.1	3.3	7.1
April	22.0	12.2	17.1	57.7	4.3	4.2

تأثير أنظمة الري المختلفة على نمو وإنتاجية أربعة أصناف مصرية من بنجر السكر

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بنجر السكر (*Beta vulgaris* L.) هو نبات يزرع من أجل جذره عالي التركيز من السكروز، والذي يستخدم في البيئات الصناعية لإنتاج السكر. وبسبب التغيرات المناخية التي أدت إلى ندرة المياه، لجأت العديد من البلدان إلى استخدام أنظمة الري الحديثة لتوفير المياه وتعظيم الاستفادة من أصول المياه المتاحة. في هذا التقييم، أجريت تجربتان ميدانيتان في المركز القومي لبحوث المياه، معهد بحوث إدارة المياه، محطة مريوط، محافظة الإسكندرية، خلال موسمي الخريف ٢٠٢١/٢٢ و٢٠٢٢/٢٣. وأجريت هذه الدراسة لتقييم سلوك وخصائص المحصول لأربعة أصناف من بنجر السكر تحت أطر مختلفة لأنظمة المياه (التنقيط والرش والتحاميل). أنتجت أنظمة الري بالتنقيط والتحاميل أعلى قيم لمؤشرات المحصول الكمية عند ١٨٠ يومًا بعد الزراعة في كلا الموسمين، بما في ذلك وزن الجذر، ومحصول الجذر، ومحصول القمة الطازجة، مقارنة بأنظمة الري بالرش في كلا الموسمين ومحصول السكر في الموسم الأول فقط. في الموسم الأول، أنتجت أنظمة الري بالتنقيط والري بالحفر أكبر محيط للجذور مقارنة بأنظمة الري بالرش. استخدمت البنجر السكري المزروع تحت الري بالتنقيط ١٤,٢٪ مياه أقل من تلك المزروعة تحت الري بالرش و٣٥,٦٪ مياه أقل من تلك المزروعة تحت الري بالحفر. علاوة على ذلك، أنتجت أصناف المونوجرام (BTS3980 وBTS3975) أعلى القيم في محصول الجذور ومحصول السكر ومحصول القمة الطازجة مقارنة بأصناف البوليجيرم (أوسكار و بيراميد) في كلا الموسمين.